TITLE: The Yo-Yo Story: An Electronics Analysis Case History

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VOLUME: 5 ISSUE: Winter YEAR: 1961

STUDIES IN INTELLIGENCE

A collection of articles on the historical, operational, doctrinal, and theoretical aspects of intelligence.

Exemplary but unusual history of the detection and reconstruction of a Soviet missile-guidance system.

THE YO-YO STORY:
An Electronics Analysis Case History

Charles R. Ahern

Electronic components are a critical part of modern weapons systems, less dispensable than some of their more obviously important features. It is possible to conceive of an air defense system without interceptor aircraft, for example, but it is not possible to conceive of one without electronic devices, systems, and techniques. Intelligence on the electronic portions of Soviet weapons systems has therefore become a key item in our knowledge of these systems. Here is a case history of community teamwork in gaining such intelligence on an unprecedented type of radar control for surface-to-air missiles in the Soviet air defense system. The story features a concerted effort to obtain observations, an imaginative analysis, a lucky break, and an excellent follow-through by research and development.

Herringbones and Ventilators

In the early 1950's U.S. and British intelligence posted a lookout for signs of the Soviet deployment of surface-to-air missiles in readiness for defense against air attack. Toward the end of 1953 some unusual road networks were seen outside of Moscow, which, although they did not have the anticipated configuration of missile sites, were at least located at points where missile installations might be expected. As the pattern of these locations began to develop a more intense search for them was made. By the autumn of 1954 quite a number of reports consistently described the networks as comprising three more or less parallel roads a mile long intersected by some ten cross roads about a half mile in length in a herringbone pattern. There was nothing in the reports that would particularly excite the curiosity of the specialist in electronics intelligence.

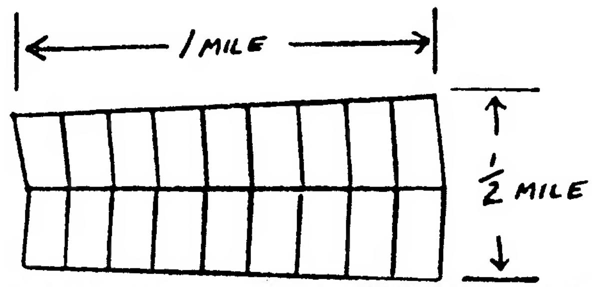

Figure 1. Herringbone Road Complex

During the last quarter of that year U.S. and UK attachés began to report details of other features around the herringbone complexes in the Moscow area. In September a British observer, without making specific reference to it in the body of his report, indicated in a sketch that there was a "barracks area" some distance away, more or less in line with the axis of the herringbone and connected with it by a road. After a couple of weeks this report was amplified and a different possible barracks area located. The original "barracks," according to the revised description, seemed to be a long grass-covered bunker with a concrete hand-stand at one end. The observer noted that large ventilators at this end of the bunker flapped with what seemed extraordinary violence, even when the fairly high wind blowing at the time was taken into consideration.

A week later, when two U.S. attachés were a half hour out from Moscow on a plane bound for Leningrad, one of them noticed an unusual installation on the ground. It had a look of newness and activity about it. He didn't get a very clear impression of any buildings on the site; his eye was caught by the motion of two large wheels installed in a pit with a ramp leading down to them. Each wheel, he reported, was like a thin yo-yo, with twin flat disks spinning at an angle to the horizontal. He estimated their speed at about 60 rpm and said they appeared to wobble on their axes. He had difficulty describing the nature of this wobble; it appeared to be a kind of "even undulation throwing the outside edges [of the disks] a foot or two from their planes of rotation." His sketch is shown in Figure 2.

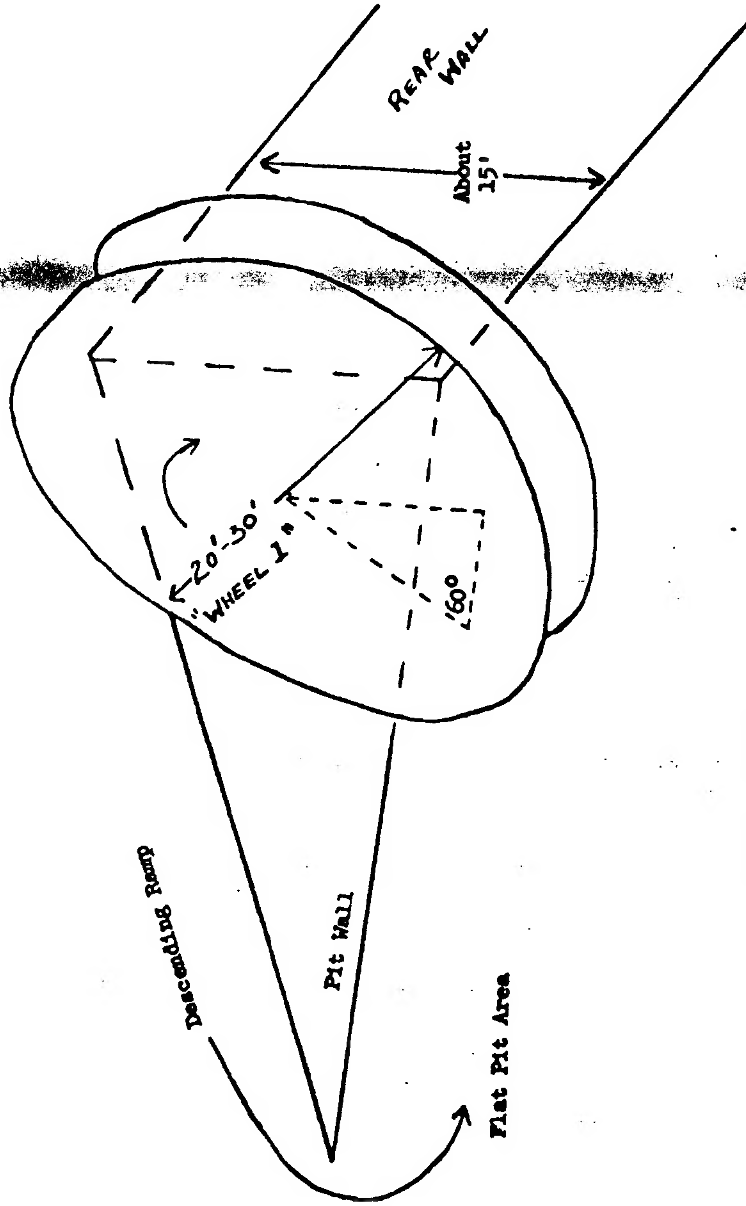

Figure 2. Observer's Sketch of Yo-Yo

This report proved to be a remarkably accurate description of the device thereupon nicknamed the Yo-Yo,[1] considering that the observer had only five or ten seconds to take in the details of something never before seen or heard of. His companion on the flight, seated on the other side of the plane, had in the course of the trip spotted one of the herringbone sites, and when he returned to Moscow a few days later he reported it in response to the standing order for observations on these. When the two men checked their observation times they realized that the Yo-Yo and the herringbone had been seen simultaneously, and that there might be a connection between them. They astutely guessed that the Yo-Yo might represent some kind of missile guidance system, and this comment in the report brought it to the attention of electronics intelligence analysts.

A month later, about the beginning of December, British observers riding on a train southeast of Moscow noticed a fenced area with a microwave antenna on a pole at one end. In the center of the enclosure there was an earth bunker with one open end facing the pole. There they saw a "double rotating disk array," each disk, they judged, about ten feet in diameter and making about 120 revolutions per minute. The plane of the disks was inclined at about 45 degrees from the horizontal. The observers had the impression that the disks either had serrated edges or were polygonal structures given a disk-like appearance by the rotation.

In February 1955 this same site was observed and photographed by U.S. personnel. Their photography was not of a scale or quality to convey any clear idea of the shape of the Yo-Yo, but their observations, erroneous in part, did correct and refine some of the earlier information. They reported that the two disks were each about 20 feet in diameter and about 12 inches thick. They thought them both vertical, at right angles to each other. They were not sure whether they were double, and if so whether the two halves rotated in the same or opposite directions. They estimated the rotation to

[1] Soviet Bloc electronics items are assigned *nicknames*, as opposed to code names or cover names, to provide a common nomenclature in the collection and production of intelligence. These nicknames are selected and agreed upon on a tripartite basis among electronics intelligence representatives of the United States, the UK, and Canada.

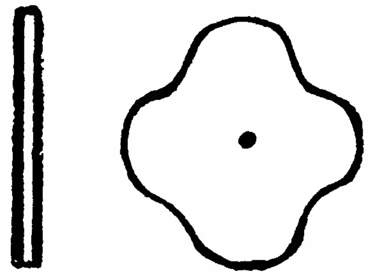

Figure 3. Sketch of Disks Seen One on Edge and One Full-face.

be about 40 rpm and stated that there was no wobble, an optical illusion of one being given by the viewing angle and the serrated edges. Figure 3 is a sketch supplied with this report.

At this stage it was by no means clear that the herringbone complexes had anything to do with missiles. No missile had been seen on the sites, and the road arrangement would have been equally suitable to housing development or crop or ammunition storage. Even if they were surface-to-air missile sites, it was not firmly established that the Yo-Yo was uniquely related to them. Further, there was nothing about the Yo-Yo to indicate that it was an electronic device; the reports on it did not even convey any clear idea of what it looked like. One offhand opinion received from British experts was that it might be a rock crusher.

Nevertheless, under the good-humored assumption that "if no one can figure out what it is, it must be electronics," the Yo-Yo reports were laid before the joint gatherings of community electronics specialists at that time sponsored by the old Military Electronics Working Group. Beginning in January 1955, the Yo-Yo was brought up at each meeting of the MEWG for many months. For the present, however, there was little that the electronics analyst could do but speculate as to what the observers had really seen and request more detailed information, especially photographs.

By the summer of 1955 it had become more or less clear that the Yo-Yo did bear a specific relationship to the herringbone complexes. The herringbones were arranged so that their length was always along a radial line from Moscow. The Yo-Yo bunker was situated on this same line, centered on the herringbone, and always about a mile nearer to Moscow. The

Yo-Yo itself was invariably at the herringbone end of the bunker. But the true shape and appearance of the Yo-Yo remained uncertain.

Early in August 1955 a packet of photographs was brought to CIA electronics analysts. Picturing a Yo-Yo southeast of Moscow, they had been taken, happily, from several different angles. These photographs revealed, at last, what the Yo-Yo really looked like. The observers had for the past year been more or less correctly and accurately describing what they had seen, but the descriptions were incomplete. The "disks" were truncated equilateral triangles assembled in pairs in the Star of David configuration. There were two such assemblies, one in the vertical Moscow-herringbone plane and the other (of which an edge is visible in the accompanying reproduction) at right angles tilting up 45 degrees from the horizontal toward the herringbone. The early "violent flapping of the ventilators" and wobbling wheels were now comprehensible optical interpretations of the two assemblies in rotation.

Analysis and Synthesis

The analyst, as is usually the case in electronics intelligence, thus found himself confronted with a fully developed Soviet device deployed in the field. In these circumstances his task is one of unravelling what the Soviet designer was

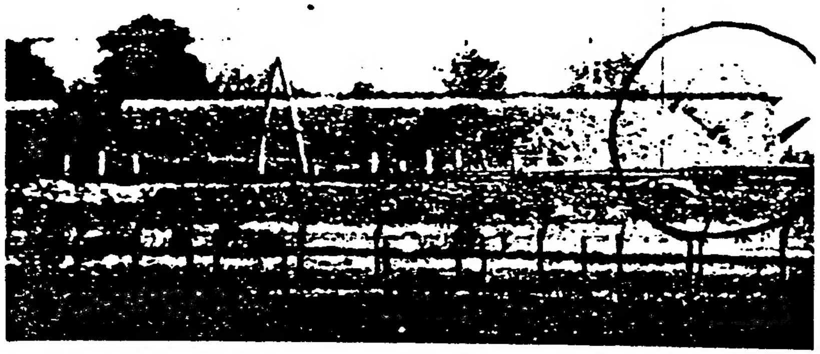

Figure 4. Photograph of Bunker with Yo-Yos at Right End

attempting to achieve, the reverse of the original design process. Whereas the Soviet designer is given a set of performance specifications and proceeds by selecting available techniques, components, and production processes and by making the inevitable technical compromises to reach his final design, the analyst must work backward from the finished design to arrive at the designer's objective. In this process he must also take care that his thinking is not controlled by concepts of how an item would be designed in the United States: the Soviet concept of equipment use is usually quite different from ours, at least in electronics.

In the absence of any similar, previously known piece of equipment from which to extrapolate, the analysis of the Yo-Yo problem had to begin with a basic assumption as to the general purpose of the device—that it was designed to control surface-to-air missiles launched from the herringbone area (though no missiles had yet been seen). Granted this assumption, the problem became that of figuring out how missiles could be guided by an apparatus with such an appearance as that shown in the photos and the placement and behavior described in the observer reports. The analytic point of departure was the consideration that, however the Yo-Yo worked to guide the assumed missiles, it would have to provide information with sufficient accuracy on both the missile's target and the missile itself in three coordinates—range, elevation, and azimuth.

In virtually all surface-to-air missile guidance systems this tracking of the missile and its target is done by a system of radar antennas, say of parabolic form, that point toward missile and target and focus beams of radio energy on them, much as a searchlight does with its visible beam. Before the Yo-Yo photos were received the possibility could not be ruled out that it too was such a large parabolic reflector imperfectly observed and poorly described; but the form shown in the photos was clearly no conventional variety of antenna system. All the available descriptive information indicated that the Yo-Yo disks retained their relative position while rotating. This meant that only the edges of the disks could point upward and away from Moscow, the direction in which radar antennas should be looking for enemy aircraft and should guide missiles to attack them. The straight sections of these

edges seemed the most likely portion for antenna apertures. This reasoning provided the germ of a solution.

The straight sections were about 20 feet long and perhaps 8 inches wide. An aperture of these proportions could be expected to produce a transverse fan beam about 30 times as broad in the plane of its short dimension as in that of its length.[3] Given the orientation, arrangement, and rotation pattern of the disks, it appeared that on each rotation of each two-disk assembly six of these narrow beams, one from each straight edge, would scan a volume of space extending above and beyond the herringbone complexes. The size and number of the apertures had apparently been one of the requirements on the mechanical designer: since six would have made a huge, unwieldy single disk, he had divided them between two Star-of-David triangles.

The six beams from the tilted Yo-Yo would thus scan the air approaches to Moscow in azimuth and those from the vertical assembly would scan it in elevation. Both sets could provide range data on any target or missile in the volume of space scanned. With the whole volume covered, the antennas would not need, like a searchlight or parabolic radar, to stop scanning in order to follow a target or the defense missile, but would provide position data on these in the course of continued scanning. In such a system, therefore called "track-while-scan," memory devices would be needed to develop the track by maintaining continuity of information during the intervals between the individual antenna scans. Such devices were considered possible.

A series of calculations, based on guided missile performance requirements as well as radar needs, were then undertaken. Guided missile analysts furnished estimates of the probable range of Soviet surface-to-air missiles and the size of their warheads. The former provided limits for certain technical characteristics affecting the range requirement of the radar; the latter helped define its accuracy requirements. In all, two dozen or more technical factors entered the calculations. These had to be weighed against one another in reaching the compromises that are always forced upon the system designer:

[3] The dimensions of the beam are inversely proportional to those of the aperture that produces it.

for example, if the operating frequency were too low, accuracy would be poor and transmitter power requirements excessive; if it were too high, the rapid scanning rate of the antennas and the narrowness of the beams would make too few pulses hit the target.

As the design for a missile guidance system evolved from this process, a check was made with analysts in the field of vacuum tubes and other electronic components to insure that it did not call for techniques or components beyond Soviet capabilities. Finally a design was established that took into consideration the missile, the operating principle of its guidance, the technical characteristics of the radar, the accuracy of the system, and its anticipated capabilities.

One task remained—to re-examine the entire solution against any possible alternatives in the light of all reports and photographs, inquiring whether everything reported could be accounted for in the solution and whether anything required by the solution and not reported would seriously weaken it. Each alternative solution that came to mind failed to account for some aspect of the reported data or required a capability on the part of Soviet technology that appeared unreasonable. One suggestion, for example, was that the Yo-Yo antennas would simply radiate energy to illuminate the target for a homing system in the missile. Such a system might work, but because of the discontinuous nature of the radar signal it would require the inclusion of memory devices in the homing gear of each missile. This elaborate provision seemed unlikely. Furthermore, the homing illumination theory was inconsistent with the configuration of the Yo-Yos: a single pair of disks should give adequate illumination, so the two at right angles to each other would be an unnecessary complication.

Testing the tentative answer to a problem is a fairly standard procedure, but testing this answer was a particularly demanding task because of its startling implications. If it was right, the Soviets had not continued in the direction taken by the original German wartime development of surface-to-air missile guidance nor in that of postwar Western efforts, which were based on extensions of the German work. Instead, making a clean break with precedent, they had arrived at a design that was inherently capable of dealing with multiple

targets simultaneously. The data on the target or targets were apparently translated automatically into missile command guidance; there were no indications of a homing system on the missile.

This analysis, which required some three weeks from the time the photos were received, was made the basis for a Provisional Scientific Intelligence Report incorporating its conclusions and presenting a list of probable technical parameters.[8] The publication of the report would ordinarily have been the end of the matter, but the Yo-Yo story is unique. For one thing, the report found, with its unprecedented conclusions, a by no means unanimous initial acceptance among the elements of the intelligence community concerned with electronics and guided missiles. For another, it was brought in December 1955, through a series of steps initiated by Army intelligence, before the Technical Advisory Committee on Electronics of the Assistant Secretary of Defense for Research and Development, and the Committee recommended that a project be initiated to build a prototype or mock-up of the Yo-Yo as therein conceived. The mock-up technique, used during World War II, had led to an assessment of the capabilities of the German radars and was invaluable in developing electronic countermeasures to foil them, but its use had not been common in the decade following the war.

In March 1956, at about the same time it became fairly well established that missiles were actually emplaced on the herringbone complexes, the mock-up contract was let through Army Ordnance and work on it begun.

Exploitation of a Break

Meanwhile the Dragon Returnee Program had been working on repatriated German scientists and technicians who had been taken to the U.S.S.R. after the war. Many of these gave information of some value to electronics and guided missile intelligence, but it appeared that the Soviets had carefully kept the German electronics specialists insulated from developmental work in military electronics, especially in the heavy radar field, where the results of Soviet efforts were becoming increasingly evident from other sources. After sev-

[8] Provisional Scientific Intelligence Report, CIA/SI 51-55, 6 Oct. 1955, "YO-YO, A Possible Soviet Missile Guidance System."

eral years of experience with returnees, the chances of finding one who knew about the development of specific high priority electronics items were privately judged at about one in ten thousand.

In the fall of 1956, however, a year after the publication of the Yo-Yo analysis, one of the Dragon returnees, Christian Sorge, who it was thought might have information on a different missile system, called attention during his routine preliminary debriefing to a new development on which he had worked from 1950 to 1952, a system for guiding surface-to-air missiles called the B–200. He said that it used a very strange-looking antenna system, which he then sketched on a sheet of paper for the interrogator. The interrogator, looking at

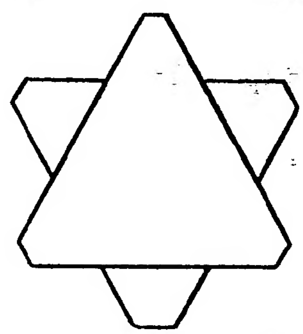

Figure 5. Sorge's Sketch of B–200 Antenna

the superimposed equilateral triangles Sorge had drawn, recalled the published Yo-Yo analysis and realized with considerable excitement that Sorge had knowledge more important than had been supposed. As the preliminary debriefing continued, the identity of the B–200 with the analytic conception of the Yo-Yo was established at some dozen points.

The intelligence community now organized a team of specialists to assist in Sorge's debriefing. Their efforts brought out more and more technical details, especially of the memory portion of the system, the complex electronic tracking circuitry made necessary by the adoption of a guidance system dependent on the discontinuous data of scanning antennas. It was this critical part of the B–200 system, fortunately, that Sorge had worked on. By the time his debriefing had

been completed he had provided many new insights, as well as having confirmed some 25 or 30 facts hypothesized in the analytic reconstruction. One curious reaction to the initial correlation between the analytic report of October 1955 and Sorge's information had been the suspicion that the report might have fallen into KGB hands, who through Sorge were now feeding it back to the interrogator. This fear was quickly dispelled by the amount of detail and consistency in Sorge's data.

Sorge said that he and several others, having signed contracts with the Soviet authorities for additional work in 1950 and 1951, had been assigned tasks on the B–200 system, which had apparently been conceived by 1949. In addition to the details of circuit designs, he described some of the testing programs for the prototype that began in 1952, and his information was supplemented by that from some of the others who had returned. But in 1952 they had all been removed from B–200 development and placed in non-sensitive activities for a cooling-off period of three or four years prior to repatriation.

Follow-Through by R&D

The group of specialists assisting in the debriefing of Sorge included personnel from the Diamond Ordnance Fuze Laboratory, the contractor for the Yo-Yo mock-up project. As details of the tracking system and other portions of the B–200 were brought out by interrogation, they were promptly included in the development work, effecting important changes in its direction. As a major example, although the analytic report had hypothesized a separate computer for each missile-target engagement, the DOFL people had decided that the Soviets would use a single large digital computer. Sorge's statement that separate analog computers were in fact called for in the design now brought about a timely reorientation in the mock-up project. It was fortunate that the project was already contracted for and under way when Sorge appeared: at least a year and perhaps more was saved by having a research team assembled and working on the problem before being overwhelmed by such a volume of detailed information.

As it was, the development project, begun in April 1956, did not yield a prototype installation that could be tested until early in 1958. The results of the test program showed the

Soviet B–200 to constitute a major technological advance in radar tracking systems. An additional surprise was that it performed much better than expected when tested against electronic countermeasures, jamming; but the technique of dropping chaff was effective against it if properly employed. The B–200 was found to have an angle accuracy as great as 0.05° on strong targets and a range accuracy of 25 yards; this meant that missiles in the range of 20 to 25 miles would not need a homing radar of their own. Its low-altitude capability was much better than the Germans had estimated, being limited only by the terrain around the installation.

The ability of the system to cope with multiple targets was confirmed; the ability of one installation to direct as many as 20 or 25 simultaneous target-missile interceptions, as claimed by the Germans, seems to depend only on whether the Soviets choose to provide the necessary computer for each interception.

Thus the Yo-Yo story, which began with the reports of a few alert observers who noticed some unusual installations in 1953 and 1954, ends with the tests of the mock-up system in the autumn of 1958. It raises some interesting questions, for example how quickly the Sorge information would have been believed if the Yo-Yo sites not been seen, reported, and analyzed. Even with the analytic report in hand, some of the specialists involved in the debriefing doubted much of what Sorge said in the early stages. The approach of the analytic report itself, the setting out to design a Soviet electronic system on the basis of its physical appearance, was unique; it succeeded largely because the design was so different from anything theretofore developed.

The concern of electronics analysts about the new Soviet guidance system has remained undiminished, because our information on its internal workings ends with the 1950–1953 period, and what the Soviets may have done in the intervening years to improve its performance is a continuing problem. Several studies have considered what improvements *could* be made in the B–200, but no intelligence information has come to light on any that *have* been made. And now the recent appearance of a second-generation missile guidance system, Fruit Set, which might be loosely described as a mobile Yo-Yo, is tending to push the original B–200 into the background.